Agriculture & Food Security

RESEARCH

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The effect of traditional agricultural practices on the food consumption of households facing extreme weather events in Tanzania

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Abstract

Background An estimated 140 million people in Africa face acute malnutrition. By impacting agricultural production, climate change is likely to further decrease food consumption, particularly in sub-Saharan African states. Against this backdrop, various actors have called for more attention to alternative farming and food systems based on traditional agricultural knowledge capable of ensuring access to sufficient, nutritious, and safe food. So far, however, we have limited systematic evidence on which traditional agricultural practices may promote the food resilience of households exposed to extreme climatic conditions. Focusing on the most prevalent traditional diversification practices in Tanzania, this study assesses the extent to which crop diversification, annual crop intercropping, crop-tree intercropping, crop-livestock integration, and the cultivation of traditional crops increase the food availability and dietary diversity of smallholders facing extreme weather events in Tanzania.

Methods We combine temperature and rain data with information on farming practices and food consumption information provided by the Living Standards Measurement Study–Integrated Surveys on Agriculture for more than 25,000 Tanzanian households nationwide. We rely on a matched differences-in-differences approach to account for selection bias and allow for causal inference.

Results Our matching models consistently show that the planting of traditional crops (in particular sorghum) promotes dietary diversity and reduces the need for food rationing in households experiencing climate shocks. In contrast, households relying on maize cultivation show less dietary diversity and increased food rationing behavior. In addition, we find that—under extreme weather conditions—crop diversification furthers households' dietary diversity, and crop-livestock integration, as well as crop-tree intercropping, seem to reduce households' need to ration food.

Conclusion and policy recommendation This study has important implications for policymakers. In light of climate change and weather variability, it underscores the need to better integrate indigenous knowledge into farming systems. Our results call for greater dissemination of traditional diversification strategies and more reliance on indigenous, drought-tolerant crops. Traditional farming practices can function as a safety net, protecting smallholders in Tanzania against the detrimental consequences of weather shocks.

Keywords Traditional agricultural practices, Agricultural diversification, Food consumption, Climate change, Tanzania

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Introduction

According to the 2022 Global Report on Food Crises [1], at least one in five people in Africa goes to bed hungry and an estimated 140 million people face acute food insecurity. Climate change is expected to exacerbate this effect, ultimately leading to a significant decline in crop yields (e.g., [2–4]). For example, the Intergovernmental Panel on Climate Change (IPCC) [5] predicts a decline in 20–40% of maize yields and a 20–60% reduction in wheat yields in certain African regions, pushing the vast number of already poor people deeper into poverty [6].

In light of the pessimistic climate-related predictions regarding crop yields, a growing world population, and the pressing need for climate change mitigation and adaptation, scholars and policymakers have increasingly debated different strategies for transforming agricultural systems and food production to promote climate resilience [7]. One dominant discourse within this debate argues for increased mechanization, technological innovations, monocultures of high-yield crops, and agrochemical inputs to secure food production and access (e.g., [8, 9]). However, various studies have increasingly questioned this productivist viewpoint (e.g., [10–12]). They have argued that the pursued land-use intensification is rarely associated with positive ecosystem services and a reduction in malnutrition [13–15].

As a result, calls for more attention to local traditional practices and better integration of indigenous knowledge into food systems have mounted over the last years ([7, 16]). Several positive features of traditional agricultural systems have been underlined, including biodiversity conservation, low energy inputs and implementation costs, enhanced food consumption, and climate change mitigation [17, 18]. Different articles in *Agriculture & Food Security* have, for example, analyzed the role of crop diversification—a widely employed traditional farming technique—in promoting food security [19, 20]. Contrasting different perspectives on how to reshape agricultural systems, Singh and Singh [7

While a mounting number of studies have shown how the integration of traditional agricultural practices may positively affect different food-related outcomes (e.g., [21–23]), the literature has rarely assessed the effectiveness of these practices on the food consumption of households exposed to extreme weather events. So far, we have no systematic evidence on how different traditional agricultural practices affect the food resilience[1] of households facing climate shocks based on quasi-experimental research designs.

To address this gap in the literature, this study analyzes the impact of different traditional agricultural practices on the food consumption (food diversity and food rationing behavior) of smallholders facing extreme weather shocks in Tanzania. We thereby concentrate on traditional practices that promote diversity, are highly prevalent among farmers in Tanzania, and have been sufficiently covered by the survey data employed in our analysis. Matching Tanzanian households on a series of essential covariates based on the Living Standard Measurement Survey–Integrated Surveys on Agriculture (LSMS–ISA), we assess the extent to which the implementation of crop diversification, intercropping, crop-tree diversification, and crop-livestock integration may attenuate the detrimental effect of weather variability. In addition, we assess the impact of cultivating the widely planted traditional crops sorghum and cassava on farmers' food resilience.

Empirically, our statistical models consistently show that the cultivation of traditional crops (in particular sorghum) promotes dietary diversity and reduces the need for food rationing in households experiencing climate shocks. The planting of the cash crop maize, in contrast, has the opposite effect. In addition, we find that—under extreme weather conditions—crop diversification is an effective strategy to ensure households' dietary diversity. Crop-livestock integration and crop-tree intercropping seem to reduce households' need to ration food when they face climatic shocks.

This study contributes to the literature on the adaptive capacity of farming systems in three important ways. First, although some studies have linked particular traditional agricultural practices to food security, they have limited external validity (e.g., [24]). To overcome this, we rely on panel survey data covering the whole of Tanzania. We use a quasi-experimental design combining a matching procedure with a difference-in-difference design. As a result, we do not only attempt to increase external validity but also are able to make causal inferences. Second, previous studies on the determinants and effects of implementing particular traditional agricultural practices have primarily focused on examining one isolated practice, such as crop diversification or agroforestry (e.g., [19, 25]). In doing so, they have largely ignored the fact that households can implement several practices at the same time. As a result, we have little knowledge of which specific diversification practice might be most effective when it comes to increasing food consumption among farmers exposed to extreme weather events. Finally, our work is among the first to effectively test the impact of various traditional practices on food outcomes in light of climate shocks.

This study proceeds as follows: in the literature overview, we discuss existing research on the link between weather variability and traditional farming practices. Thereafter, we discuss how these practices may be causally linked to food outcomes. Our case selection, data, and method are presented in the subsequent section,

[1] When referring to food resilience, we follow the definition advanced by FAO [107] stating that food resilience can be viewed as the ability of households to ensure the intake of sufficient and nutritious food during times of shocks, stresses, and crises (such as extreme weather events).

followed by the analysis and discussion of the results. This study concludes by highlighting potential policy implications and providing some recommendations for future research.

Traditional agricultural practices and food consumption

Tackling food insecurity is one of the most significant challenges of our time [26]. Climate change is an essential factor influencing food availability (e.g., [5]). Climate assessments for Africa conclude that the continent will become warmer and drier [5], and increasingly variable rainfall is anticipated, especially in the east [27]. In addition, an increase in extreme weather events (both droughts and floods) is forecasted [28]. By directly impacting agricultural yields, these weather changes hamper the access to nutritious food of large populations in the Global South (e.g., [29]). The fact that many African countries are heavily dependent on rain-fed agriculture and are characterized by high poverty levels and limited state capacity further exacerbates the adverse effects of climate change on food security [30, 31]. In light of the expected detrimental effects of climate change-induced weather variability on food accessibility, it is no surprise that scholars and policymakers are increasingly investigating the adaptive capacity of farming systems [17].

Scholars have stressed the potential role of traditional agricultural practices in ensuring access to food in light of increasing weather variability ([7, 16]). Traditional farming practices are based on indigenous knowledge and shaped by the local socio-ecological and cultural context. Employed by a large share of the world's farming population, particularly in Africa, these practices are often viewed as sustainable systems that are in equilibrium with surrounding ecosystems [32]. Examples of traditional farming practices include multi-cropping, intercropping, the use of organic fertilizers and traditional crops, agroforestry, terracing, crop rotation, and crop-livestock integration [33]. Traditional farming systems can provide important ecosystem services by, for example, ensuring soil health, conserving water, reducing chemical inputs, and promoting biodiversity. Adopting traditional agricultural practices, in fact, may offer solutions to securing access to sufficient, nutritious, and safe food in environments of high climate risk (e.g., [13, 16]).

In this study, we decided to focus on traditional practices that promote diversity, are widely employed in Tanzania, and are sufficiently covered by the employed LSMS–ISA survey data. In particular, we test the effect of four commonly used traditional diversification strategies: crop diversification, annual crop intercropping, crop-tree intercropping, and crop-livestock integration. We additionally assess the impact of widely cultivated indigenous crops on the food consumption of households experiencing weather shocks.[2]

Crop diversification is the practice of cultivating more than one variety of crops belonging to the same or different species in a given area (e.g., [34, 35]). A specific form of promoting crop diversity is intercropping, the simultaneous cultivation of multiple crops on the same field [36]. Both crop diversification as well as intercropping practices are likely to stabilize crop yields. They provide insurance, or a buffer, against environmental fluctuations, because different species and varieties occupy different niches and respond differently to environmental change. If one species fails, another can play its role, leading to more stable and predictable crop yields [37, 38]. Due to different harvesting times of the grown crops, diversification and intercropping may also increase the availability of home-produced food over the year. Moreover, both techniques considerably enrich the soil with nitrogen [36] and may reduce the risks of diseases and pests (e.g., [38, 39]).

These two practices have often been linked to different food-related outcomes. For instance, Kerr et al. [40] stress that intercropping is positively associated with household food and nutritional security in low- and middle-income countries. This mirrors findings showing that crop diversification is an important strategy for building resilience in food systems as it increases crop yields [37]. In a decade-long monitoring study, Li et al. [41] showed that maize–legume intercropping systems, on average, outperformed monocultures by 22% in grain yield. Crop diversification and intercropping are also linked to other food-related outcomes. In a study on Malawi, for instance, households that cultivate a diverse range of crops were more likely to have greater dietary diversity [42], eat more vitamin-rich foods [43], and reduce the level of worry about food adequacy and the number of nights one has to go to bed hungry [19]. Similar results were found in Tanzania, in which crop diversity was found to positively influence household dietary diversity [44] or in Ethiopia and Ghana, where crop diversification among rural households positively and significantly affected household food security [20, 45].

Another potentially important traditional agricultural practice is that of crop-tree intercropping, i.e., the mixed cultivation of woody perennials and annual crops in the same field [46]. This practice does not only produce a large number of food and non-food products, including fruits, oils, timber, latex, biomass for energy production,

[2] We will further elaborate on the choice of our tested practices and crops in the upcoming section.

and medicines that can treat diseases, but it can also contribute to the provision of important ecosystem services by, for example, replenishing underground water, capturing and storing carbon from the atmosphere, improving soil fertility, creating microclimates with lower mean air temperatures, and promoting biodiversity (e.g., [24]).

In comparison with the agricultural practice of crop diversification and intercropping, relatively few studies have been conducted on how crop-tree diversification influences food-related outcomes. Some important exceptions are worth mentioning. Thorlakson and Neyfeldt [47] stress that this practice improves farm productivity and household wealth. Kenyan farmers planting trees among their crops noticed improved farm productivity by decreasing soil erosion and increasing soil fertility. Similar results were found in Rwanda, where Ndoli et al. [48] showed that tree density increased food security, especially among smallholders with relatively large farms. In addition, Kristjanson et al. [49] find a robust positive relationship between the adoption of agroforestry farming in Ethiopia, Kenya, Uganda, and the United Republic of Tanzania and food security. However, whether adoption had induced more food security or vice-versa was not determined. Coulibaly et al. [50] confirmed this result for Malawi.

Another traditional agricultural practice that emphasizes diversification is crop-livestock integration, i.e., the management of crops and livestock on a single farm [51]. A significant advantage of this practice is that crop residues can be used as fodder for livestock, while livestock can improve soil fertility ([52]. Several studies have noted a positive effect of crop-livestock diversification on different food-related outcomes. For example, Sekaran et al. [51] show that adopting this practice can enhance household dietary diversification the available protein and energy in a household's diet. In addition, Danso-Abbeam et al. [53] demonstrates that a higher intensity of crop-livestock diversification translates into a greater probability of achieving food security among Ghanese households. This mirrors results focusing on Ethiopia, showing that crop-livestock diversification significantly influences food energy levels [54].

Besides stressing the implementation of traditional agricultural practices, scholars have recently begun to emphasize the importance of planting more drought-resistance traditional crops rather than cash crops as a way of mitigating the potential adverse effects of climate change and its related weather variability. A precise definition of traditional crops is elusive as it encompasses leafy and root vegetables, leaves from trees, herbaceous species, and fruits [55]. In general, we consider a traditional crop as an indigenous species native to a specific region that, due to prolonged use, has naturalized and become part of the culture of a community [56]. In most countries, the production of these traditional crops has declined over the years due to a lack of planting materials, low interest by seed companies, and changes in eating habits. Yet, these crops are usually more affordable and are richer in macro and micronutrients [56]. In addition, it is argued that they are better able to withstand pests and diseases and are more tolerant to drought, heat, and low-fertility soils ([57, 58]). Although traditional crops are linked to these favorable properties, little research has been conducted on whether these crops influence food availability. A few exceptions are worth noting. Van der Merwe et al. [55] show that traditional food crops, such as sorghum, sweet potatoes, and amaranth, have the greatest potential to decrease food insecurity. Lulekal et al. [59] underline that households often use traditional plants in Ethiopia as supplementary, seasonal, or survival food sources that play an important role in combatting food insecurity. This is also confirmed in Tanzania, where John [60] highlights the significance of indigenous and exotic crops for various food security measures.

Contribution to the literature

Although the studies reviewed above have significantly advanced our understanding of how traditional practices may influence food-related outcomes, we can identify several gaps in the literature that we attempt to overcome in this study. First and foremost, the above-reviewed studies do not take weather variability into account. That is, we do not know the extent to which certain traditional agricultural practices foster the food resilience of farmers facing extreme weather events. In other words, can traditional practices provide effective climate adaptive capacity by promoting the food security of households facing extreme weather events?

Second, the literature has primarily focused on particular regions of a given country and has mainly relied on interviews and surveys, leading to calls for implementing randomized controlled trials and more rigorous quasi-experimental impact evaluations of agricultural practices by some scholars (e.g., [24]). Only a few studies have employed quasi-experimental research designs to assess a potential causal link between these practices and food-related outcomes. Azzarri et al. [61], for example, show with the help of a mediation analysis that intercropping promotes households' nutritional diversity in Malawi by increasing agricultural output. In addition, Kangmennaang et al. [21] use a difference-in-difference approach to demonstrate that participation in an agroecological development project positively impacts food security in Malawi. Employing panel data and fixed effects models, Mofya-Mukuka and Hichaambwa [62] also report that crop diversification had a significant positive impact on the food availability and consumption of rural farm households in Zambia. Santoso et al. [63] show via a cluster-randomized trial that an agroecology intervention improves children's dietary diversity and reduces household food insecurity in rural Tanzania. In line with these researchers, we assess the link between traditional agricultural practices, food consumption, and weather variability with sophisticated quasi-experimental methods. That is, we combine coarsened exact matching with a differences-in-differences estimation as proposed by Bertoni et al. [64]. This allows us to control for potential selection bias and time-invariant unobservable factors, providing a more solid causal identification strategy and higher external validity.

Finally, most of the above-reviewed studies focus on examining the effect of one traditional agricultural practice on different food security measures. However, in doing so, they have neglected the fact that many farmers employ several traditional methods at the same time. To overcome this, we examine all four traditional methods and the effectiveness of cultivating traditional crops, allowing us to shed more light on which traditional practices may enhance the climate resilience of smallholders in Tanzania compared to others.

Methods

Study area

To assess the impact of traditional farming practices on the food consumption of households facing extreme weather events, we focus on the adaptive capabilities of households across Tanzania. Tanzania is seen as a country that is especially at risk of experiencing the negative effects of climate change [65]. Climate projections foresee a marked increase in temperature, rainfall, floods, and droughts in various Tanzanian regions within the next few decades [66]. At the same time, it is predicted that the Tanzanian population is likely to grow considerably, while hunger and poverty will remain high or rise [65, 67].

Tanzania's agricultural sector contributes to nearly one-third of the country's gross domestic product and employs 75 percent of the population [68]. Smallholder farmers are the backbone of the Tanzanian agricultural sector, they produce nearly 69 percent of the country's food, but only roughly half produce enough to sell [69, 70]. The average farm size for small-scale farmers ranges between 0.9 and 3 ha. Around 62% of land preparation on cultivated land relies entirely on manual labor with hand-tool technology [71

Traditional agricultural practices under consideration

According to case studies, the traditional diversification strategies that are most commonly applied by rural households in Tanzania include intercropping, crop diversification, crop rotation, improved seed variety, and crop-livestock integration [23, 72, 73]. Information on most of these practices is also sufficiently covered by the LSMS surveys. We have enough observations to test the effect of the following four practices: crop diversification, crop-livestock integration, annual crop intercropping, and crop-tree intercropping. In addition to testing how the practices mentioned above may enhance food resilience in households exposed to climate shocks, we also investigate the effectiveness of traditional crops believed to be more drought-resistant. In Tanzania, households mainly rely on the drought-relevant crops cassava and sorghum and—to a minor extent—finger millet and Bambara groundnut [60]. As shown in Fig. 2, cassava and sorghum are indeed the most prevalent drought-resistant crops in our sample. We compare the effect of both crops with the widely planted cash crop maize.

Data

To address our research question, we relied on panel data from the LSMS–ISA for Tanzania, conducted in 2010 and 2012, two survey rounds with an identical sample (the same individuals were surveyed in both years). These are representative surveys undertaken by the World Bank focusing on improving microdata quality to better inform development policies. The data contains information on the farm, village, and district levels. At the farm level, the LSMS–ISA includes information on agricultural production, inputs, number and size of plots, land ownership status, non-farm income-generating activities, consumption expenditures, and other critical socioeconomic characteristics. In addition, the surveys cover detailed plot information, including agricultural practices, type of employed labor, use of various inputs such as fertilizers and pesticides, employment of machinery and equipment, and irrigation system, among others. Our unit of analysis was households. Figure 2 depicts the distribution of our included households across Tanzania. As the figure shows, many of our included households were based in the North-Western regions, Dar es Salam, or in the southeast of the country, reflecting the population density of Tanzania.

We specifically rely on the survey waves from 2010 and 2012 for two reasons. First, in 2011, a major drought affected all East African countries, including Tanzania, where nearly half a million people were affected [74, 75]. In 2011, parts of the country experienced near-complete failure of the long rainy season [76]. We use this severe weather shock to analyze what agricultural practices make households more resilient against such extreme events. Second, the proximity of the two waves, collected merely 2 years apart with the drought occurring between the waves, presents a notable advantage for our research design. The temporal closeness mitigates the risk of confounding variables and unobserved heterogeneity that might emerge with greater time lapses between sampling points, strengthening our confidence in the presented findings.[3]

Measuring food consumption

Measuring food-related outcomes is challenging, and many scholars have criticized existing measurements. For example, Barrett [77] argues that past studies have overly relied on dietary energy availability when operationalizing the concept. Others have focused their criticism on the multidimensional concept of food security (e.g., [78, 79]). Wheeler and Von Braun [26] criticize existing food security measurements as they have largely ignored dimensions such as access and utilization of food products.

In this study, we focus on two elements of food consumption, mirroring existing research (e.g., [78]): food (dietary) diversity and food rationing behavior. First, dietary diversity measurement is one of the most straightforward tools to assess the variety of food consumed at the population level and is endorsed by many international agencies [80]. It is a qualitative measure of food consumption that reflects household access to a variety of foods and is also a proxy for the nutrient adequacy of individuals' diets [80]. It captures the number of food groups consumed in the past 7 days and is considered an acceptable proxy for food consumption ([78, 81]). Important to note is that there is no consensus on the number of food groups used in the index [78]. In this study, we construct an additive index indicating the number of days members of the households consumed the following food groups over the past 1 week: nuts and pulses (1), vegetables (2), meat, fish and animal products (3), fruits (4), milk/milk products (5). We decided to exclude the categories cereals and roots from our index as—in our data—these are dominated by white flour products with relatively low nutritious value. The dietary diversity score (DDS) is calculated by summing up the number of days the household consumed each of these five food groups during the past 7 days. The value ranges from 0 to 35, in which the lowest DDS value signifies higher food insecurity status and vice versa.

Second, we also use an indicator directly related to measuring food rationing behavior, the so-called Coping Strategy Index (CSI). This measure considers the severity of the strategies that households use to cope with deficits in their food consumption. It estimates the cumulative frequency of eight potential food reduction strategies over 7 days within each household.[4] The frequency of each behavior is weighted by its severity [78]. This variable ranges from 0 to 98, with lower values indicating less rationing and, therefore, lower food insecurity status and vice versa.

Measuring extreme weather events

We relied on the widely used Standardized Precipitation Evapotranspiration Index (SPEI), first proposed by Vicente-Serrano et al. [82], to measure extreme weather events. They computed local deviations from the average water balance, i.e., precipitation levels minus potential evapotranspiration, at a 0.5×0.5 degree resolution. As a result, the SPEI index incorporates both deviations in temperature and precipitation. Consequently, the index can better track dry or wet conditions than previously employed indices, such as the Standardised Precipitation Index or Palmer Drought Severity Index (e.g., [83]).

More specifically, our indicator measured whether a Tanzanian household resided in a geographical area characterized by severe or extreme dryness (SPEI below -1.5) at least once during Tanzania's growing season (January to June) of 2011. We especially looked at shocks during the growing season since previous studies (e.g., [84, 85]) have stressed that weather shocks are particularly likely to increase households' vulnerability during this period. Figure 1 shows the location of Tanzanian households and the incidences of dryness during the growing season in Tanzania in 2011.

Measuring traditional agricultural practices

Our treatment variables are measures of different traditional practices taken from the 2010 LSMS–ISA survey round. First, we measured *crop diversity* by creating a

[3] Although both employed survey rounds were conducted a longer time ago (2010 and 2012), we decided to rely on this older data for several good reasons. First, Tanzania experienced a major drought in the year 2011, right in between both waves. Second, in contrast to the remaining rounds conducted in Tanzania, there are only 1,5 years separating both waves, enabling us to test the more immediate effect of an extreme weather event on food consumption. Finally, both rounds cover exactly the same households. We cannot think of any plausible reason why the analyzed agricultural diversification strategies and the type of grown crops would have a different effect on the food consumption of Tanzanian households facing weather shocks today compared to 12 years ago.

[4] In particular, we relied on the following LSMS-ISA items: "In the past 7 days, how many days have you or someone in your household had to: Rely on less preferred food? Limit the variety of foods eaten? Limit portion size at meal-time? Reduce the number of meals eaten in a day? Restrict consumption by adults for small children to eat? Borrow food, or rely on help from a friend or relative? Have no food of any kind in your household? Go a whole day and night without eating anything?" We equally weighed all forms of rationing (limiting the frequency and amount of food consumed, such as skipping meals or eating the same meal portions every day) except for the cases where the household went "[…] a whole day and night without eating anything", which was counted as weighing as much as all forms of rationing combined.

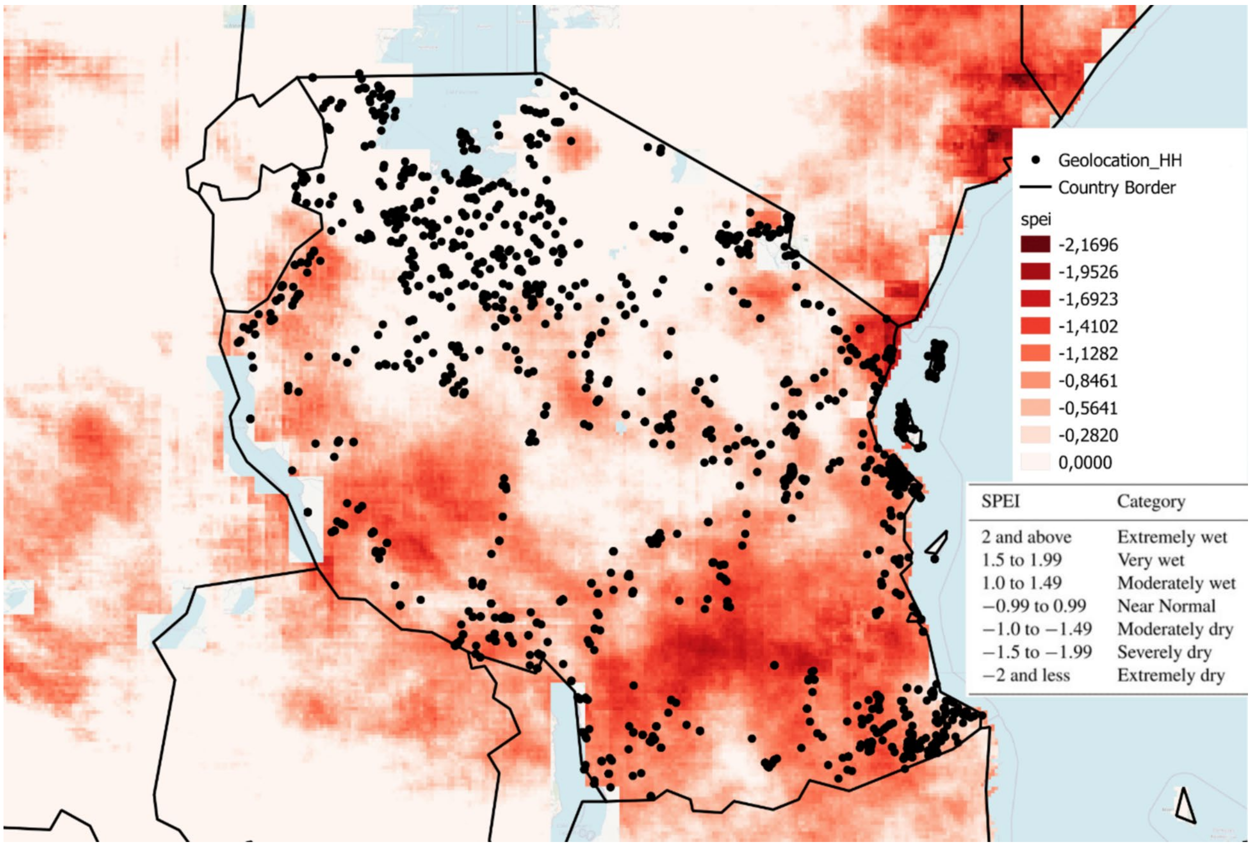

Fig. 1 Tanzanian respondents and droughts. The figure displays the drought conditions during the growing season in Tanzania in 2011, along with the location of the households in the survey. Darker colors represent worse environmental conditions. Black dots represent the location of the surveyed households

dichotomous variable, taking the value 1 if the quotient of the total number of grown crops divided by the total number of plots reported by the household is equal to or greater than 3 (and 0 otherwise). Note that this measure indicates whether a household grows more than two crops. However, these crops did not need to be intercropped. For measuring *intercropping*, we created a dichotomous variable indicating whether, across all households' plots, at least two-thirds of the harvested annual crop types were intercropped (coded as 1 and 0 otherwise). To measure *crop-tree intercropping*, we created a dichotomous variable measuring whether half or most households' plots have intercropped annual crops with fruit trees or other perennial crops, including nut trees, coffee, cocoa, and oil palm (coded as 1 and 0 otherwise). The variable *crop-livestock integration* is a dichotomous variable indicating whether households combined the cultivation of crops with livestock (small ruminants, poultry, goats, pigs, or cattle). This variable equals 1 if a household cultivated at least one annual crop and possessed livestock and 0 otherwise. Finally, we also explore the effect of cultivating the traditional crops *sorghum* and *cassava*, as well as the widely cultivated cash crop *maize*. We created a dichotomous variable for each crop, indicating if a household cultivated any of these three crops. We also considered exploring the effect of growing the drought-tolerant Bambara groundnut and finger millet. These two cultures, however, were not widespread enough in Tanzania to warrant sufficient statistical power in our quantitative empirical investigation. The prevalence of the considered agroecological practices in our sample is depicted in Fig. 2.

As can be observed, cultivating maize is by far the most common agricultural practice, while cultivating Bambara groundnut and finger millet is significantly less common. Intercropping was relatively widespread in our sample, with more than 60% of households employing it. Around one-third of households employed crop-tree intercropping and crop diversification, respectively. Crop-livestock integration was used by 13% of households. Our rather conservative operationalization can explain the low prevalence of crop diversification in our sample. We divided the total number of crop types by the total number of plots held by each household. In our analysis, a household

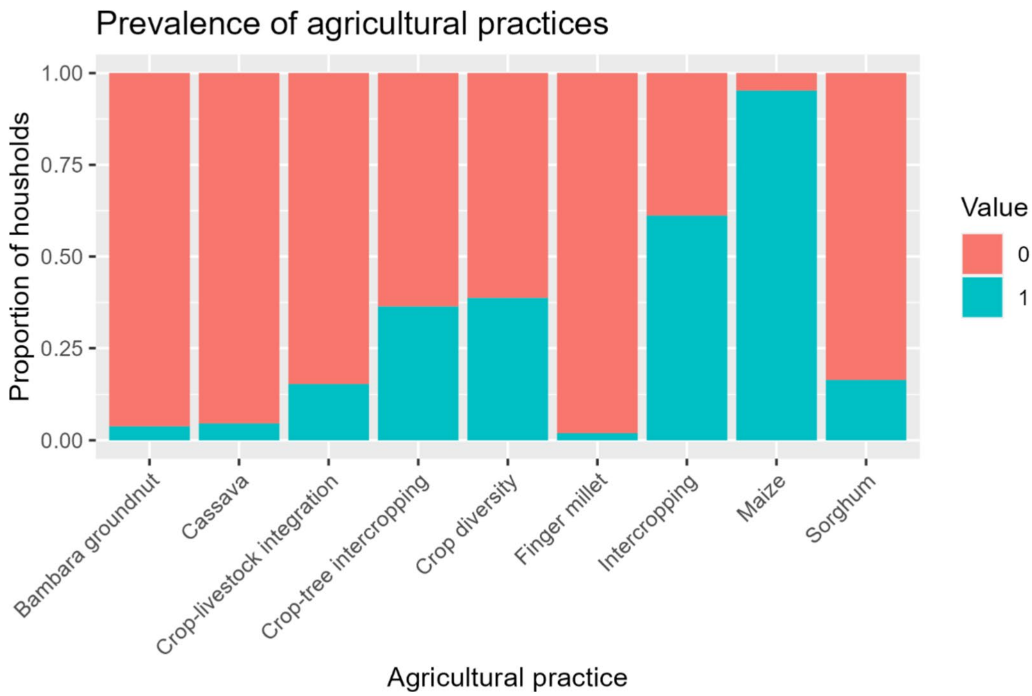

Fig. 2 Prevalence of agricultural practices. The figure displays the prevalence of agricultural practices in our sample. A value of 1 indicates that all surveyed households implemented a given practice during the 2010 survey

implemented crop diversification when it grew at least three crops in each plot. More detailed information can be found in Table A1 in the Appendix.

Empirical strategy

We estimated the treatment effect of households adopting traditional agricultural practices on food diversification and food rationing behavior and compared it with a control group. In doing so, we had to consider that implementing these practices was not random. That is, other household characteristics likely influenced the probability of households implementing a particular agricultural practice. To address this potential selection bias and to create a proper counterfactual scenario, we employed coarsened exact matching (CEM) [64]. More specifically, we matched households with similar characteristics based on a set of confounding factors, which not only influence food consumption but also the likelihood of adopting a particular agricultural practice.

CEM often provides a better reduction of any imbalance in the covariates than other matching procedures by allowing a choice of the balance between the treated and control groups *ex-ante* (rather than obtaining it *ex-post*) [64, 86]. Other matching techniques (including nearest neighbor matching, radius matching, and kernel matching) often violate the exact matching requirement by stratifying the sample ex-post on the initial covariate space (or based on the propensity score) [87]. Moreover, studies show that CEM produces better results than other matching procedures when the number of confounders is not very high (lower than 10), and most confounders are continuous variables [88]. Consequently, CEM addresses adverse selection more efficiently than other matching techniques.

Key findings from the literature and data availability determined the choice of the confounding factors that we employed for matching. More specifically, we matched households on six critical socio-economic and institutional characteristics from the 2010 LSMS–ISA survey round. These six characteristics are crucial determinants of African rural household food consumption [89]. At the same time, they may have influenced households' willingness and capabilities to implement traditional agricultural practices. First, the level of education (based on the highest educational level within a household) is a crucial factor for farm production and food access and utilization [89]. It is not only linked to employment opportunities and thereby improved access to food, but it also influences the capability of adopting particular agricultural practices. Second, off-farm employment (the percentage of household members that did any wage work other than agriculture or that were self-employed in any business other than agriculture during the last 12 months before the interview) is also an essential factor as it significantly influences a household's income, thereby directly impacting its food accessibility and utilization [90]. Third, we also control for the total number of household members under 11 years of age. The number of young children is an important factor affecting a household's food availability, consumption, and utilization. It not only reduces food consumption but may also affect the adoption of particular agricultural practices (e.g., [89, 91]). Fourth, we used a household's subjective measure of well-being as a proxy for wealth. Wealth and well-being are directly linked to food availability and may also be associated with adopting certain agricultural practices (e.g., [23, 89]). Fifth, we included a measure of tenure security (percentage of plots with ownership status equal to "owned") as greater tenure security has been found to positively affect the adoption of sustainable agricultural practices and food security [92]. Finally, to account for a local measure of state capacity, we included a variable indicating whether a household has access to piped water. Household access to (piped) water can be viewed as a proxy of state's capacity to facilitate services. State services, in turn, can influence the realization of agricultural practices and food consumption [91, 93]. Table A1 in the Appendix shows the descriptive statistics for all these socio-economic and institutional characteristics.

To estimate the effect of traditional farming practices on the food consumption of households facing climate shocks, we applied a matched difference-in-difference (DiD) estimator (e.g., [64, 94, 95]). This estimator allowed us to compare variations in food consumption between the treated (households that implemented a particular agricultural practice) and the selected controls (counterfactual households that did not enforce any of these practices) in a pre-treatment and post-treatment period. By introducing a time dimension, the DiD estimator can control for further unobserved time-invariant factors that we could not match. Our matching procedure, in turn, made the parallel trends assumption of the DiD design considerably more likely to hold.

Figure 3 displays an example of our empirical strategy focusing on crop-tree intercropping as the treatment. In the first step, we restricted our sample to the number of households that faced droughts during the growing season (January to June) of the year 2011. We classified these households into treatment or control groups depending on whether they implemented the described traditional agricultural practices (crop diversification, annual crop intercropping, crop-tree intercropping, or crop-livestock integration) in 2010. We only kept households for which no values were missing on the confounding factors.

After that, we performed the CEM procedure based on the selected control variables. More precisely, we defined the strata we used to coarsen the covariates. We categorized the level of education into five groups: no formal education, unfinished primary education, finished primary but did not start secondary education, started secondary education, and started university-level education. Around 75% of the included Tanzanian households had no household member employed outside the farm. Hence, we divided this variable into two bins: households without any off-farm employment and households with at least one person engaged in off-farm employment. We distinguished three groups concerning the number of children within a household: no children, one to three, and four or more children. We also distinguished three groups with regard to subjective well-being: 'very rich' and 'rich' were grouped in one stratum, 'comfortable' and 'can manage to get by' were grouped in another stratum, and 'never have quite enough' and 'poor' were grouped in the last stratum. To classify access to piped water, we relied on a binary grouping where one stratum was formed by households that had access to any private or public standpipe, and all other households formed the other stratum. Finally, tenure security (the percentage of plots owned by the household) was heavily skewed, where most households owned all the plots they cultivated. Consequently, we binned this variable into two groups, depending on whether a household owns all its plots. Table 1 shows the strata thresholds.

We followed Bertoni et al. [64] to assess the average treatment effects. We ran weighted linear regressions using the difference between 2010 and 2012 of our food rationing and dietary diversity indicators as dependent variables. Intuitively, this subtracted the difference in households' food consumption for the period 2012–2010 of the control group from the difference in food consumption for the period 2012–2010 of the treatment group. The weighted regression models adjusted for any remaining imbalances between the treatment and the control group. Assuming that treatment and control groups would have followed parallel trends absent the treatment, this then identifies the average treatment effect within our sample (Sample Average Treatment Effect of the Treated,SATT).

Results

Tables 2 and 3 show the results of our analysis conducted using Python and R (version 4.3.1). We examined the effect of the selected traditional farming practices on the change in food rationing (Table 2) and dietary diversity (Table 3) between 2010 and 2012, respectively. The SATT is the coefficient of the respective treatment variable as estimated from weighted linear regression models. All models include the socio-economic and institutional control variables used in the matching procedure to adjust for any remaining

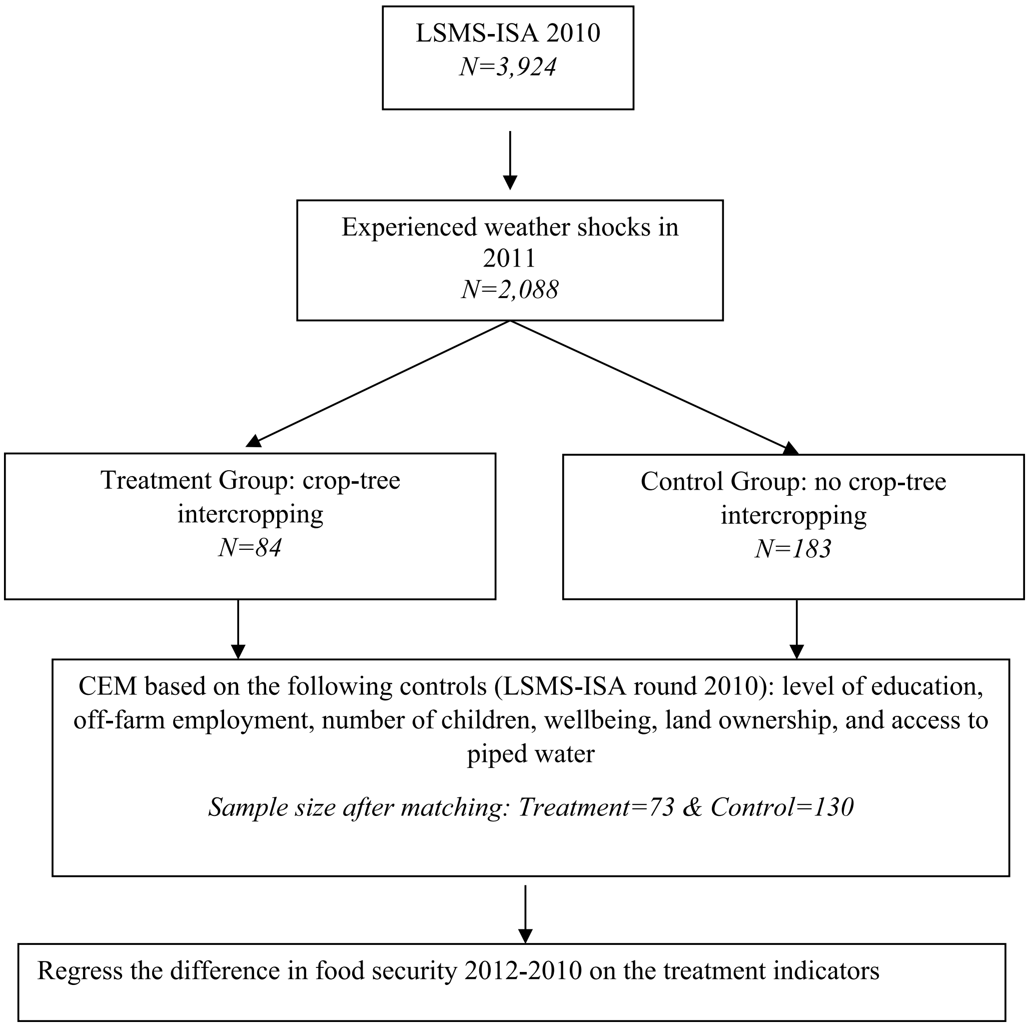

Fig. 3 Difference-in-difference CEM approach (crop-tree intercropping)

Table 1 Strata thresholds. Source: LSMS–ISA round 2010

Variable	Strata thresholds
Level of education	(1) No formal education, (2) unfinished primary education, (3) finished primary but did not start secondary education, (4) started secondary education but did not start university, and (5) started university-level education
Off-farm employment	(1) Any off-farm employment, (2) no off-farm employment
No. of children	(1) No children, (2) 1 to 3 children, (3) 4 or more children
Wellbeing	(1) Very rich, rich (2) comfortable, can manage to get by (3) never have quite enough, poor
Tenure security	(1) All plots are owned by the HH, and (2) not all plots are
Piped water	(1) Piped water, private outside standpipe, public standpipe, and (2) all else

imbalances. Standard errors were clustered at the stratum membership to guard against potential misspecifications of the regression models [96]. The complete output, including the effect of each control variable, can be found in the Appendix in Tables A2 and A3. Further information about the number of matches can be found in Tables A4–A17 in the Appendix.

As can be seen from Table 2, three agricultural practices are statistically significantly associated with reduced rationing behavior in households experiencing extreme

Table 2 Effect of agricultural practices on food rationing

	Crop diversity	Intercropping	Crop-tree intercropping	Crop-livestock integration	Cassava	Maize	Sorghum
SATT	− 0.247	2.104	− 2.214*	− 1.582*	− 2.076	12.006*	− 1.831*
	(1.190)	(2.305)	(1.142)	(0.849)	(4.970)	(6.465)	(0.985)
Num. Obs	327	209	203	252	83	157	238
Std. Errors	By: stratum	By: stratum	By: stratum	By: stratum	By: stratum	By: stratum	By: stratum

Clustered standard errors in parentheses

* $p < 0.1$

** $p < 0.05$

*** $p < 0.01$

Table 3 Effect of agricultural practices on dietary diversity

	Crop diversity	Intercropping	Crop-tree intercropping	Crop-livestock integration	Cassava	Maize	Sorghum
SATT	1.710*	0.228	− 0.428	0.366	4.507	− 4.404*	1.881**
	(0.941)	(0.768)	(1.158)	(0.849)	(2.987)	(2.022)	(0.764)
Num. Obs	287	185	171	228	68	105	216
Std. Errors	By: stratum	By: stratum	By: stratum	By: stratum	By: stratum	By: stratum	By: stratum

Clustered standard errors in parentheses

* $p < 0.1$

** $p < 0.05$

*** $p < 0.01$

weather events: *crop-tree intercropping*, *crop-livestock integration*, and the cultivation of *sorghum*. On the contrary, the cultivation of *maize* is associated with an increase in food rationing. The other agricultural practices show no statistically significant association with food rationing. Note, however, that the number of observations, especially for the cassava model, is relatively small, which might partly explain the lack of statistical significance.

To illustrate the effect sizes, consider the negative coefficient of crop-tree intercropping. The sign indicates that households that relied on this agricultural practice displayed less rationing behavior on average. The average predicted value of the food rationing score for households that did not employ crop-tree intercropping is 0.57, but -1.7 for households that practiced crop-tree intercropping. This difference corresponds to a reduction of 0.25 standard deviations in our food rationing score. The effect of cultivating maize is significantly more substantial. Relying on this staple crop increases the average model prediction of the food rationing score by 1.38 standard deviations.

Next, we tested the effect of these agricultural practices on dietary diversity. As can be observed in Table 3, *crop diversity* and cultivating *sorghum* are associated with an increase in dietary diversity, while cultivating maize is associated with a reduction in dietary diversity. The other agricultural practices show no statistically significant effect on dietary diversity. Due to the small number of observations in our *cassava* model, the lack of statistical significance for this crop needs to be interpreted with caution though.

We may again illustrate the effect sizes using the average prediction of dietary diversity for the treatment and control groups. For example, households that did not cultivate sorghum had an average predicted value of the dietary diversity score of − 1.48. In contrast, households that did cultivate sorghum had an average predicted value of − 0.2. This corresponds to an increase of 0.16 standard deviations in our dietary diversity score.

Robustness checks

To ensure the robustness of our results, we checked whether changing the composition of our strata affects our results. Instead of using the strata described in the method section, we used equally sized strata bins employing Sturge's bin rule. The results of these additional robustness checks, which can be found in Tables A18 and A19 in the Appendix, largely corroborate our main findings.

Furthermore, we assessed the robustness of our findings by relying on an alternative matching approach.

Instead of using the CEM technique, we employed the most widely employed matching method: nearest-neighbor propensity score matching [97]. As can be observed in Tables A20 and A21 in the Appendix, the results of the propensity score matching (PSM) analyses are in line to those depicted in Tables 2 and 3: crop-tree intercropping, crop-livestock integration and cultivating sorghum are able to reduce food rationing behavior, while crop diversity is able to increase dietary diversity. Note that the effect sizes and the statistical significance of the crop-tree intercropping and crop-livestock integration variables are considerably larger in the PSM models compared to our CEM specifications. These results increase our confidence that our findings were not an artifact of the employed CEM analysis.

Discussion

Two main conclusions can be drawn from the results reported above. First, cultivating traditional crop varieties that are more drought-tolerant compared to usual cash crops, such as maize, may be an effective strategy to promote food consumption and the food variety of households exposed to climate shocks. Our analysis reveals that particularly sorghum, a widely planted traditional crop in Tanzania that has heat-tolerance properties (c.f. [98]), reduces food rationing behavior and increases dietary diversity in rural households experiencing extreme climatic conditions. In contrast, we find that maize—the most planted staple crop in Tanzania—does not contribute to farmers' climate resilience. Our results indicate that households relying on maize report more food rationing and a less diverse diet after experiencing harsh climatic conditions.

This result resonates with previous findings underlining that heat shocks may severely reduce maize yields in Tanzania and directly affect children's health in a country that is highly dependent on maize production [99]. Moreover, adaptation measures such as full irrigation, deficit irrigation as well as mulch and nitrogen addition are found to be insufficient to prevent future climate-related maize yield losses [100]. Considering our results and these previous findings, Tanzanian farmers will likely profit from reducing their dependency on maize production and diversifying into traditional crops such as sorghum.

Besides highlighting the role of traditional crops, this study underlines the importance of particular traditional farming diversification strategies in improving the access to sufficient and nutritious food in households confronted with extreme weather events. Previous work has concluded that crop diversification may effectively increase food security in selected African countries [19, 20]. Building on this literature, our quasi-experimental quantitative approach shows that when Tanzanian farmers cultivate more than two crops on most of their fields, they must ration less food when exposed to adverse weather conditions. Thus, crop diversification seems to promote food intake in light of increasing climate variability.

We find two other traditional diversification practices to promote dietary diversity of households suffering from climatic stress: intercropping of annual and perennial crops as well as crop-livestock integration. While some few studies suggest that intercropping annual crops with trees may increase dietary diversity and food intake [101], hardly any work has systematically tested the impact of crop-livestock integration on food consumption (c.f. [52]). Our investigation highlights that, in fact, both traditional practices may contribute to greater dietary diversity of farmers in times of harsh climatic conditions. The interaction between crops and livestock (including small ruminants, poultry, goats, pigs, or cattle), as well as crops and particular trees and palms (including fruit and nut trees, coffee, and palm oil), can be an effective strategy to foster climate resilience in rural Tanzania.

While we find significant and consistent effects for some of the analyzed traditional agricultural practices, we do not see a significant impact for others (particularly annual crop intercropping and the cultivation of cassava). The lack of statistical significance for these two farming practices should be interpreted with care. Our estimation strategy of applying CEM and PSM in combination with a DiD approach is highly conservative. While the DiD design could account for much of the unobserved differences between treated and untreated households, it also removes much of the data's variation. By adding the CEM and PSM matching procedure, we reduced our sample size even more, which can inhibit the detection of potential effects by our regression models.

Important to note is that some limitations characterize this study, and several avenues for future research exist. First, by relying on household data, this study might not have accounted for intra-household food inequality (e.g., [102]). Considering that children and women are often more affected by the lack of food (e.g., [103]), future studies should assess the link between climate change, agricultural practices, and food security using individual-level data. Second, as Debray et al. [104] stressed, we need to promote our understanding of how the local context (socio-ecological, economic, and political settings) matters for the implementation and effectiveness of particular traditional farming practices. Knowing more about the conditions under which certain practices may be effectively implemented seems imperative for promoting local climate resilience. Third, more attention should be devoted to examining the pathways through which these practices may further food consumption. Some of these practices may facilitate individuals' access to stable, adequate, and diverse diets by, for example, promoting livelihood diversification and higher incomes, enabling direct consumption and more control over farming inputs, furthering mutual support practices, and enhancing local social capital. The validity of these mechanisms has, however, rarely been systematically tested. Finally, many of the agricultural practices occur at the same time. For instance, households might not only use crop diversification but also crop-tree integration on certain fields. More research should be devoted to studying the effect of these combinations.

Conclusion

This study examined the extent to which some of the most prevalent traditional agricultural diversification practices may increase farmers' climate resilience in Tanzania. Specifically, we investigate four diversification practices: crop diversification, annual crop intercropping, crop-tree intercropping, and crop-livestock integration. In addition, we examine how cultivating two traditional drought-tolerant crops (sorghum and cassava) affects the food consumption of households exposed to climate shocks. Our investigation is among the first to causally assess the effectiveness of these traditional farming practices in attenuating farmers' climate-related food insecurity.

Through a matched differences-in-differences approach, we showed that households that relied on crop diversification, crop-tree intercropping, crop-livestock integration, and sorghum cultivation were particularly able to maintain food consumption when facing extreme weather events. Relying on the cash crop maize, in contrast, seems to decrease the food resilience of Tanzanian households.

Our positive findings for these practices suggest that governments, nongovernmental organizations, funding agencies, international organizations, and philanthropic donors should be more willing to embrace and fund the implementation of these traditional agricultural practices. In contrast to agricultural intensification policies based on monocropping, high-yield crops and the use of synthetic inputs, traditional farming practices are cost-effective and have the potential to create essential ecosystem services. While global diets are centered around the "big three" cash crops (maize, wheat, and rice), African farmers should feel encouraged to diversify and incorporate more traditional crops and use different diversification strategies.

In collaboration with the Tanzanian government, international agencies and research organizations have implemented several important projects to assist smallholders with the adoption of diversification practices, including multicropping, agroforestry, and enhanced crop-livestock integration [105, 106]. The National Ecological Organic Agriculture Strategy (NEOAS) for 2023–2030, recently launched by the Tanzanian government, is a pertinent example of a multi-stakeholder initiative trying to better integrate traditional ecological knowledge with scientific advancements to foster food security and climate resilience throughout the country.[5] Our analysis underlines the importance of such programs aiming at recognizing and disseminating indigenous farming practices. While ongoing initiatives represent a first step in that direction, they still remain underfunded. Moreover, local states should encourage the adoption of traditional practices by, for example, guaranteeing secure land tenure system arrangements, investing in the research and dissemination of indigenous seeds, encouraging the formation of agricultural cooperatives, and facilitating smallholders' access to credit.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40066-024-00512-1.

Supplementary Material 1.

Acknowledgements
We would like to thank Maarten Schut for all his help with the data compilation. In addition, we would like to thank the participants of the European Conference on African Studies (Cologne 2023) for their comments and suggestions.

Author contributions
Conceptualization, TW; writing, TW and RH; project administration, TW; data management, NH and MB, analyses, NH and TW. All authors read and approved the final manuscript.

Funding
Open Access funding enabled and organized by Projekt DEAL. Niklas Hänze acknowledges funding by the Deutsche Forschungsgemeinschaft (DFG—German Research Foundation) under Germany's Excellence Strategy—EXC-2035/1–390681379.

Availability of data and materials
The data sets used and/or analyzed during the current study are available from the corresponding author upon request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

[5] For a full description of this initiative, see https://www.kilimo.go.tz/uploads/books/The_Tanzania_-_National_Ecological_Organic_Agriculture_Strategy.pdf.

Competing interests
The authors declare that they have no competing interests.

Received: 24 April 2024 Accepted: 9 October 2024
Published online: 10 January 2025

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